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**Cho et al.**

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(54) **SEMICONDUCTOR DEVICE WITH BURIED BITLINE AND METHOD FOR FABRICATING THE SAME**

(71) Applicant: **SK hynix Inc.**, Gyeonggi-do (KR)

(72) Inventors: **Heung-Jae Cho**, Gyeonggi-do (KR);  
**Eui-Seong Hwang**, Gyeonggi-do (KR);  
**Eun-Shil Park**, Gyeonggi-do (KR);  
**Tae-Yoon Kim**, Gyeonggi-do (KR);  
**Ju-Hyun Myung**, Gyeonggi-do (KR);  
**Kyu-Hyung Yoon**, Gyeonggi-do (KR)

(73) Assignee: **SK Hynix Inc.**, Gyeonggi-do (KR)

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**H01L 27/02** (2006.01)

**H01L 27/108** (2006.01)

**H01L 21/764** (2006.01)

(52) **U.S. Cl.**

CPC ..... **H01L 27/0203** (2013.01); **H01L 21/764**  
(2013.01); **H01L 21/76229** (2013.01); **H01L**  
**27/10876** (2013.01); **H01L 27/10885**  
(2013.01)

(58) **Field of Classification Search**

CPC ..... H01L 21/76229; H01L 27/0203;  
H01L 27/10876; H01L 27/10885; H01L  
21/764

See application file for complete search history.

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*Primary Examiner* — A. Sefer

*Assistant Examiner* — Benjamin Tzu-Hung Liu

(74) *Attorney, Agent, or Firm* — IP & T Group LLP

(57) **ABSTRACT**

A method for fabricating a semiconductor device includes forming active regions which are separated by a plurality of first trenches, forming supports which fill the first trenches; etching the active regions and defining second trenches which are shallower than the first trenches, forming spacers on sidewalls of the second trenches, etching bottoms of the second trenches and defining third trenches, forming punch-through preventing patterns which fill lower portions of the third trenches, etching sidewalls which are not protected by the punch-through preventing patterns and the spacers, and forming recessed sidewalls which face each other, and forming buried bit lines in the recessed sidewalls.

**9 Claims, 16 Drawing Sheets**

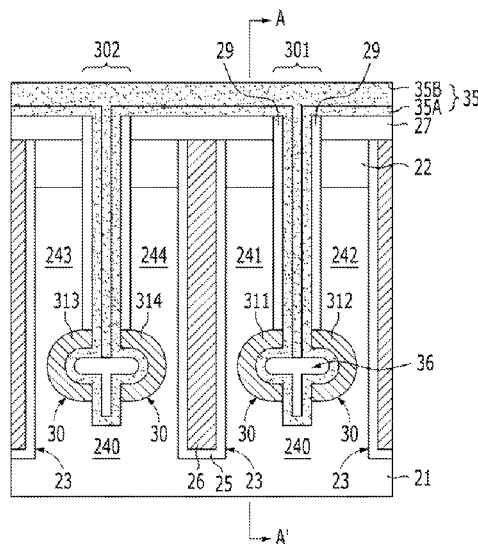


FIG. 1  
(PRIOR ART)

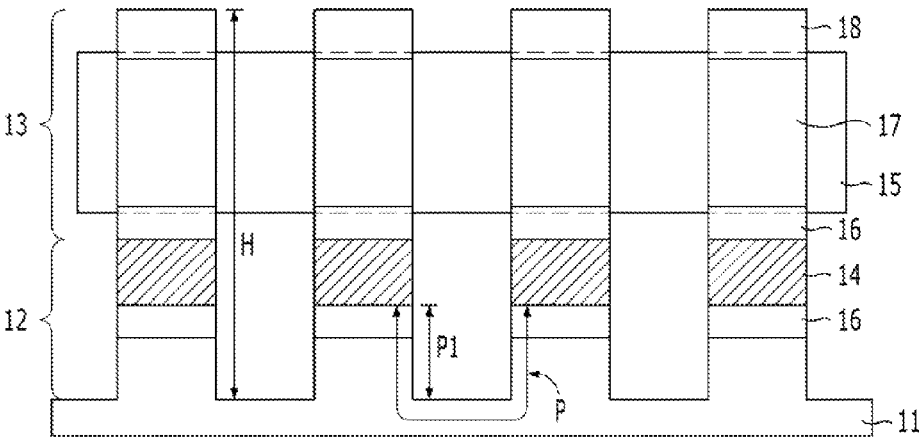


FIG. 2A

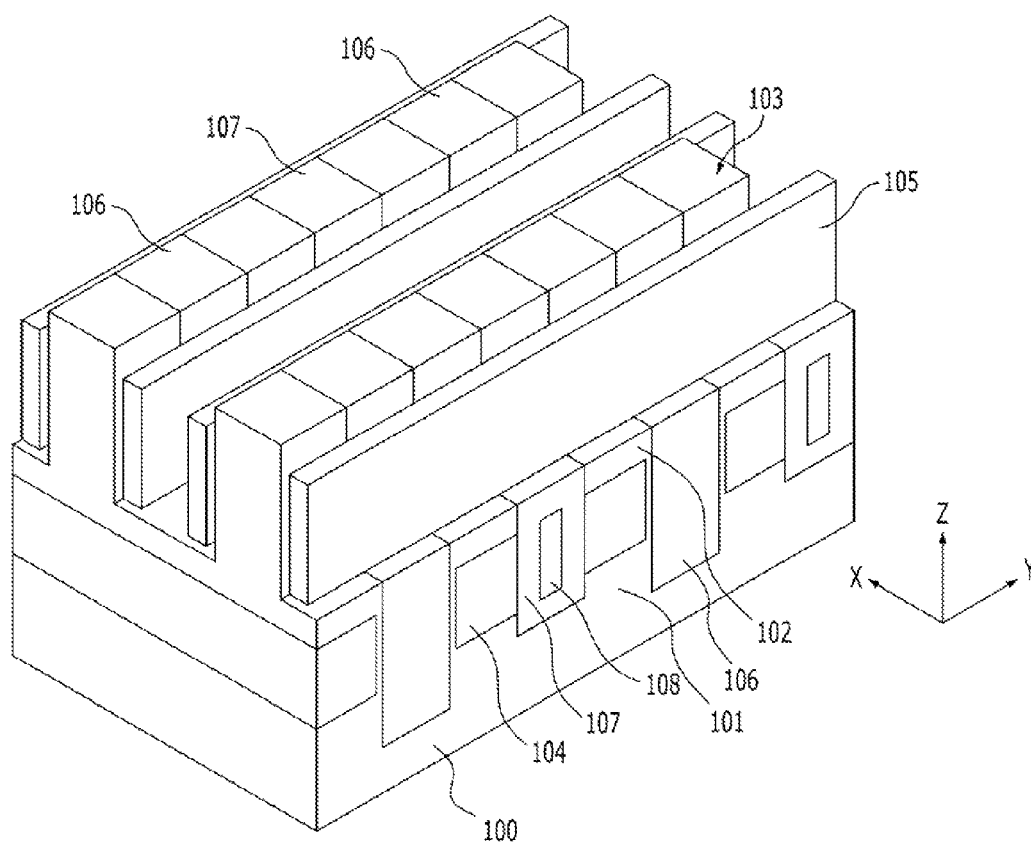


FIG. 2B

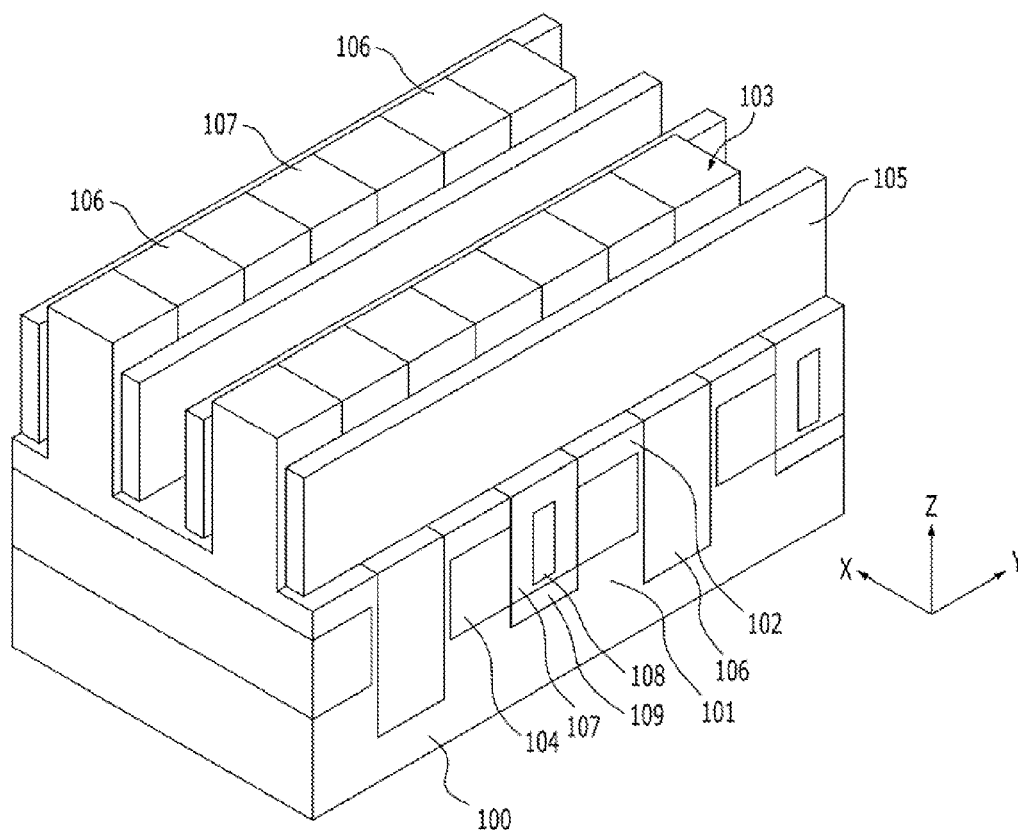


FIG. 3A

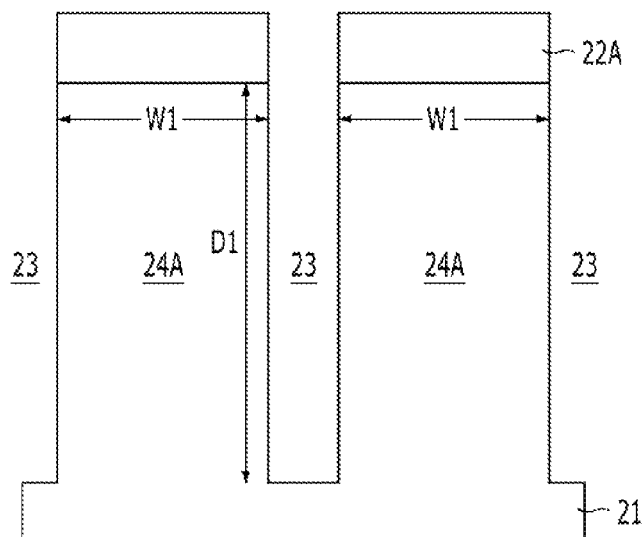


FIG. 3B

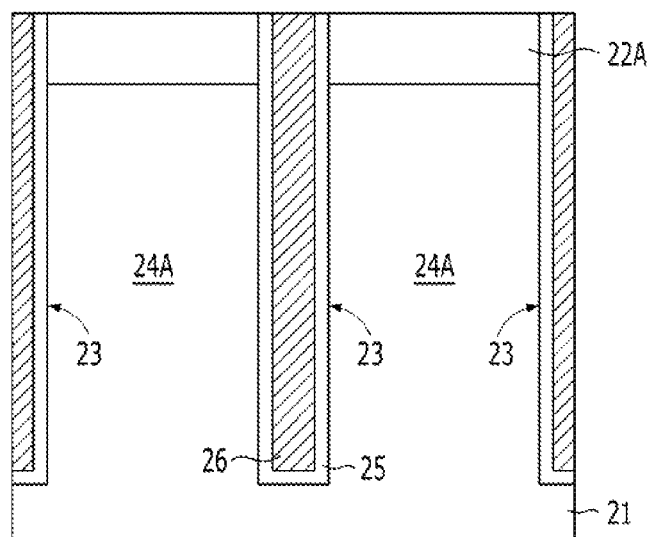


FIG. 3C

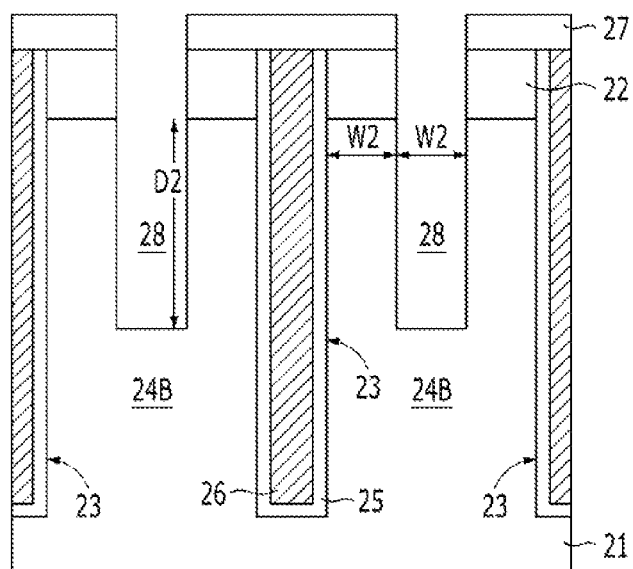


FIG. 3D

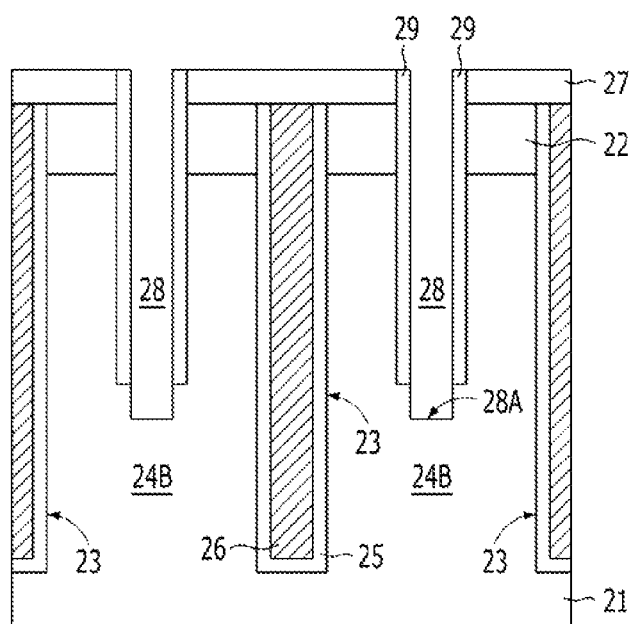


FIG. 3E

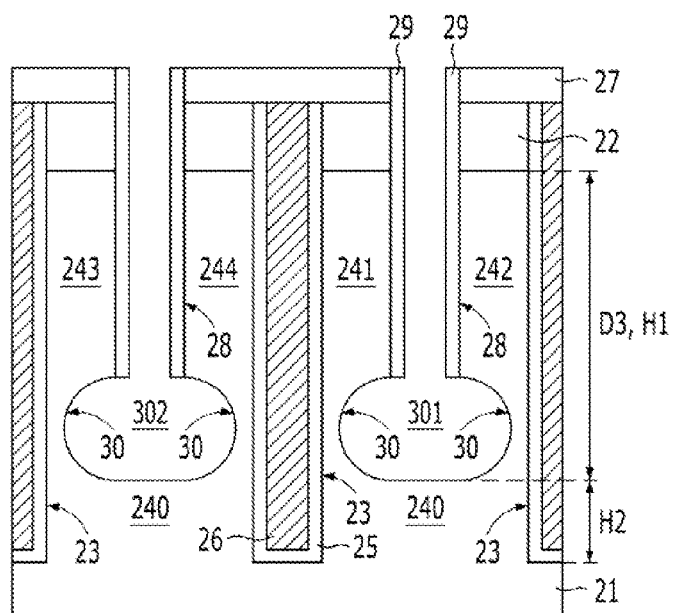


FIG. 3F

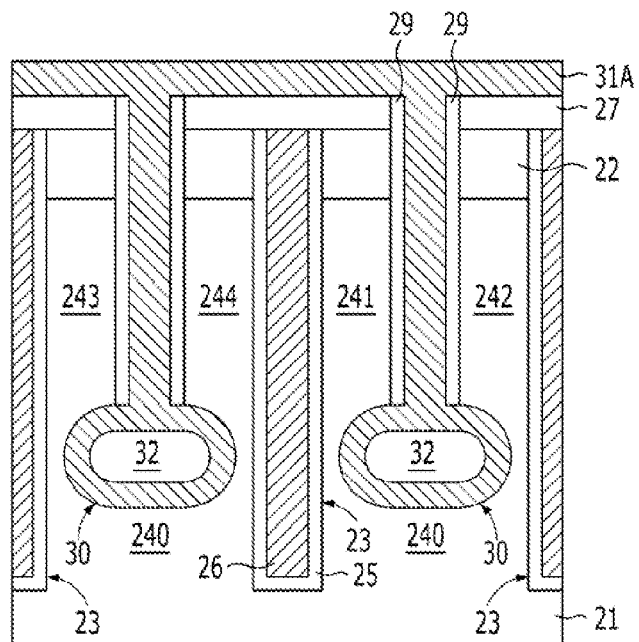


FIG. 3G

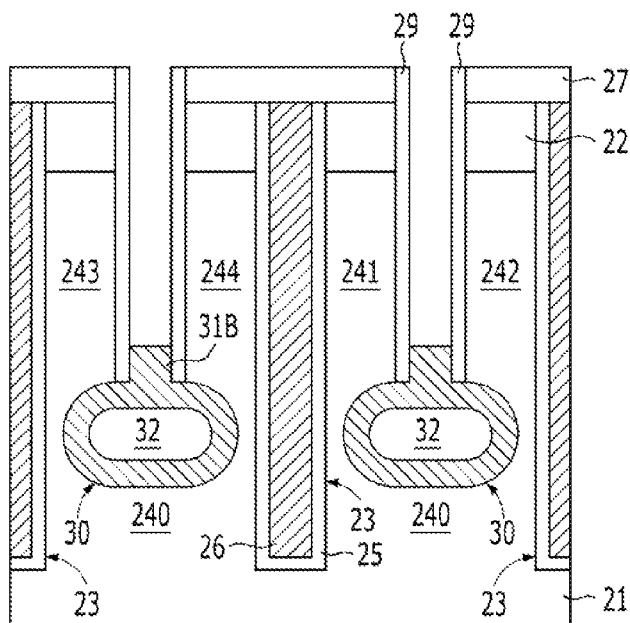


FIG. 3H

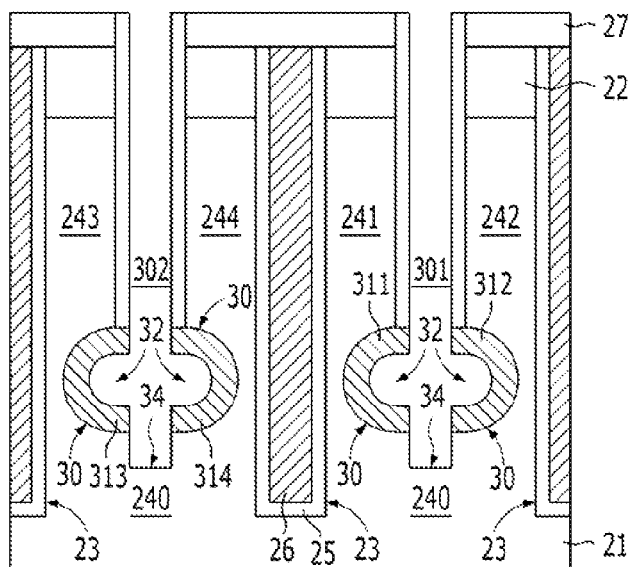






FIG. 4A

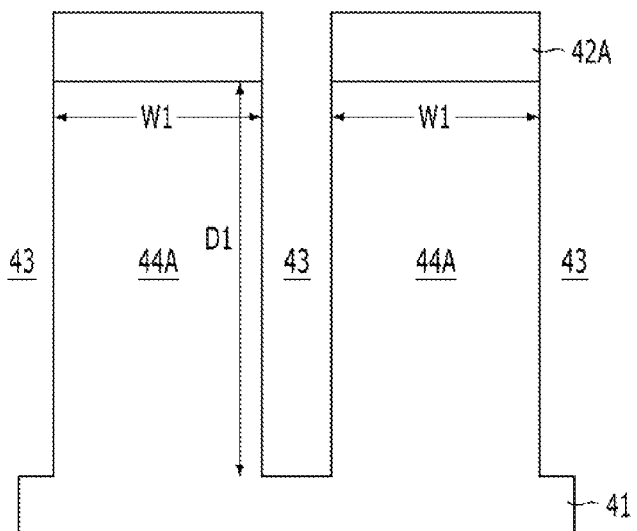


FIG. 4B

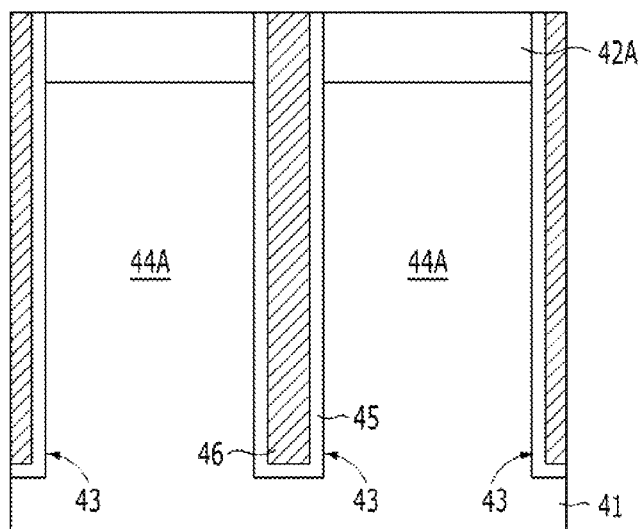


FIG. 4C

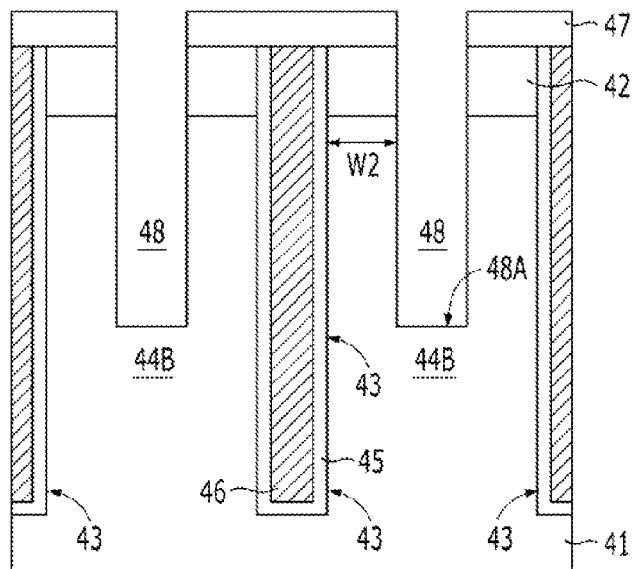


FIG. 4D

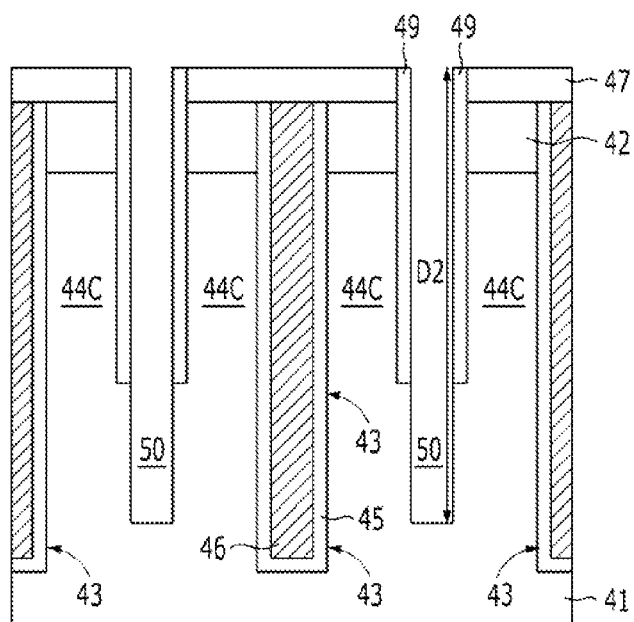


FIG. 4E

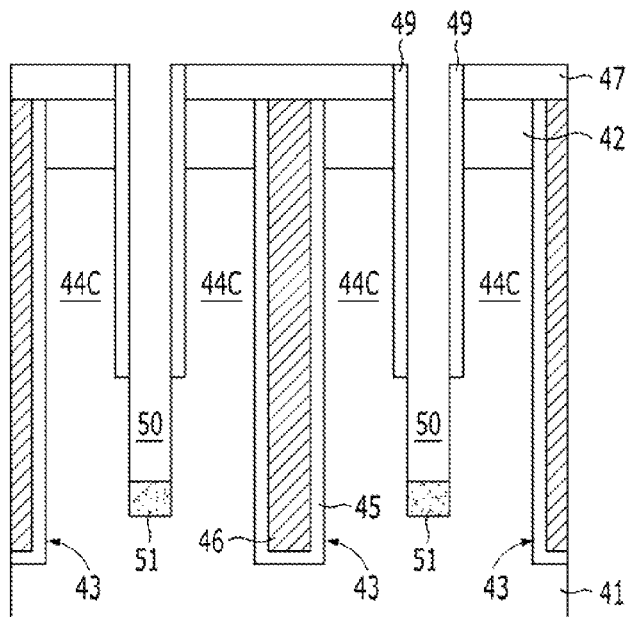


FIG. 4F

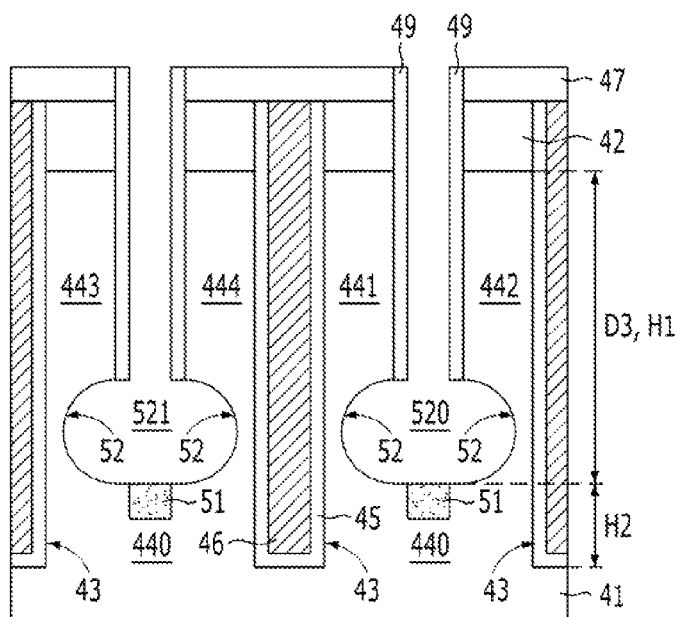


FIG. 4G

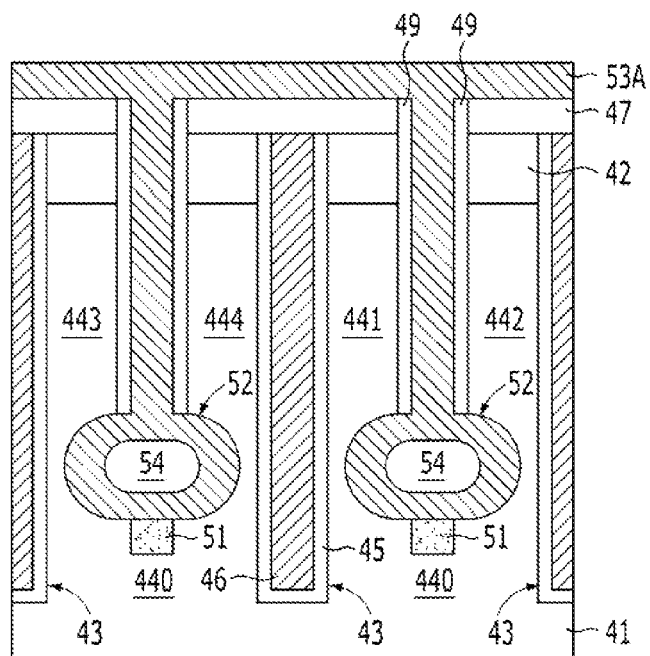


FIG. 4H

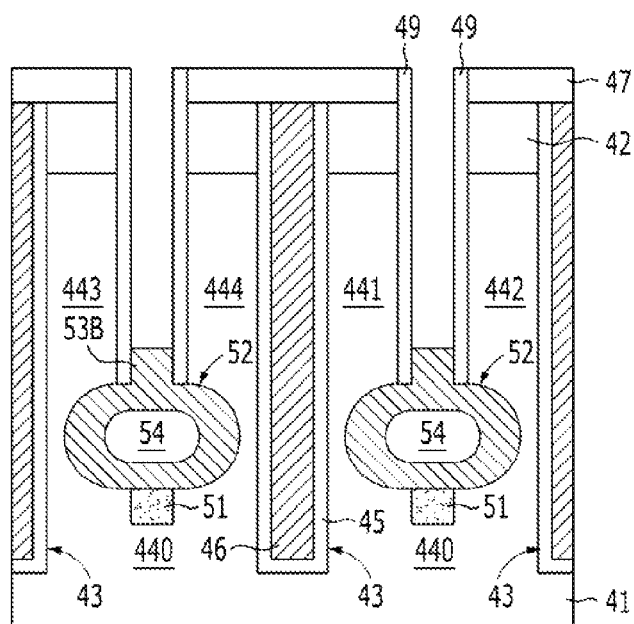


FIG. 4I

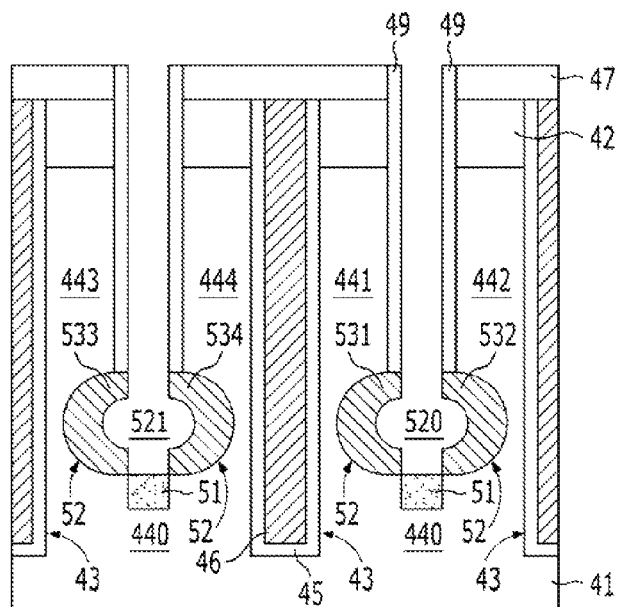


FIG. 4J

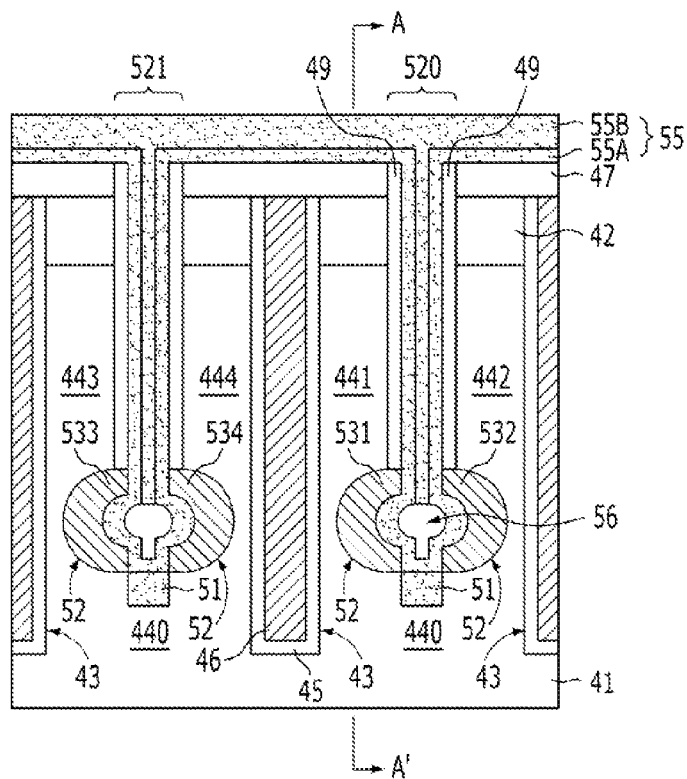


FIG. 5A

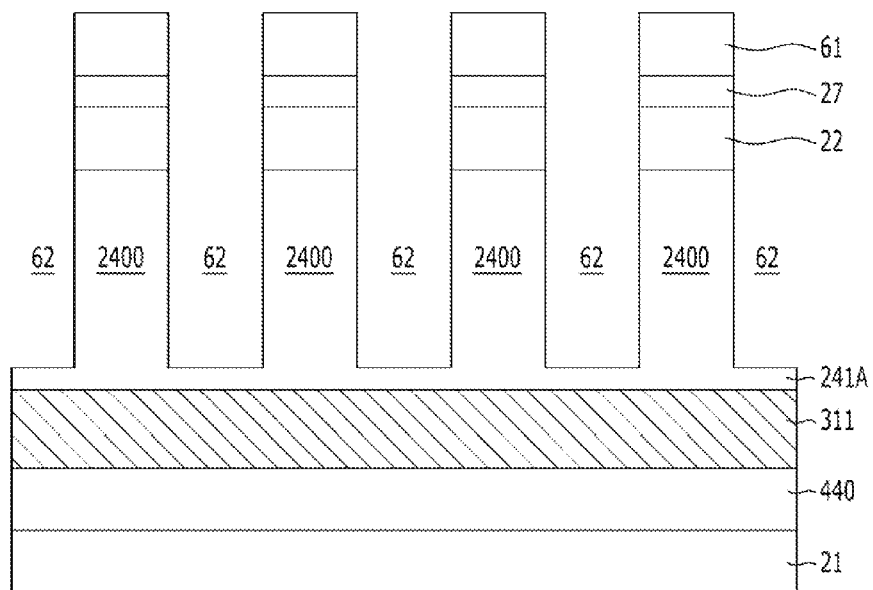
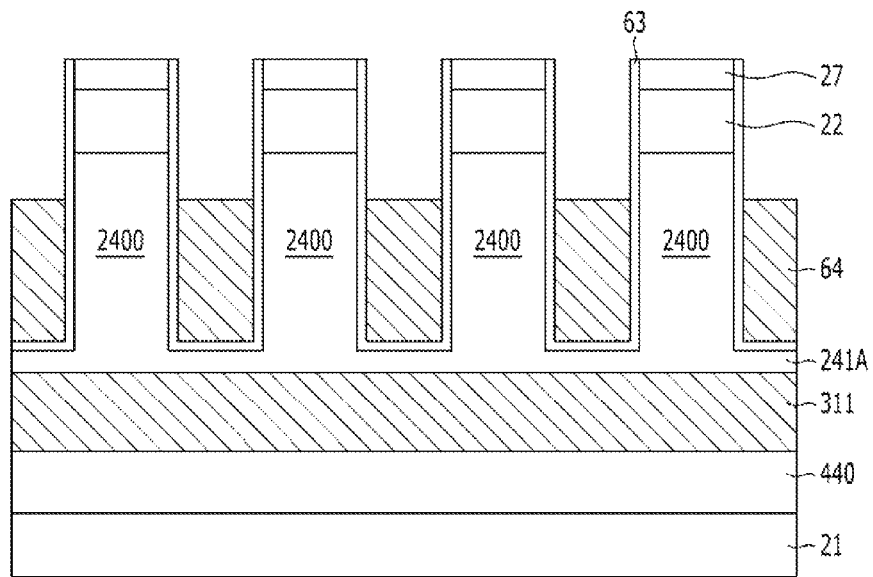


FIG. 5B



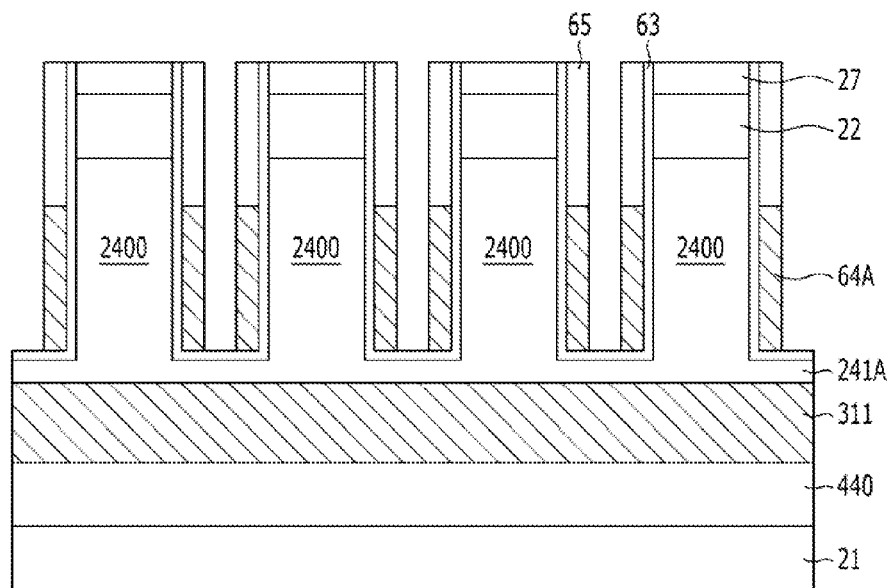
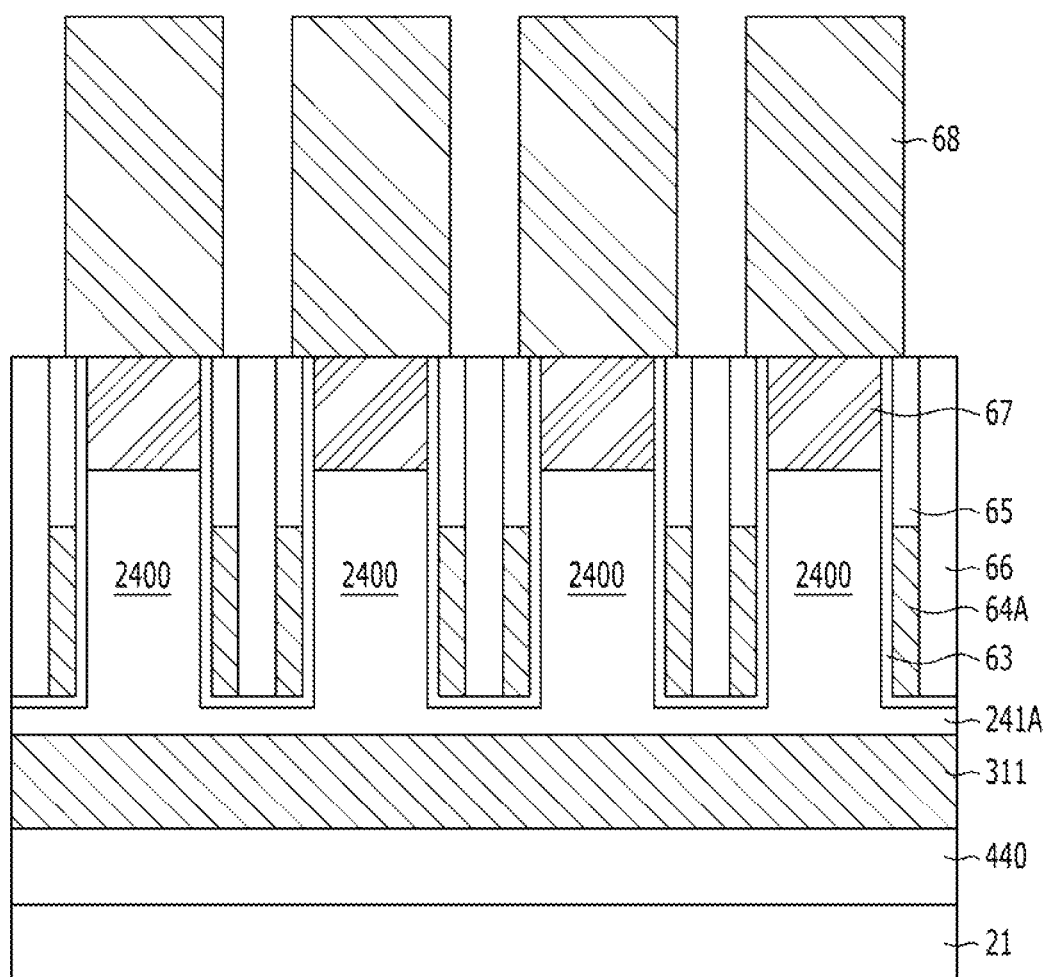




FIG. 5D



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# SEMICONDUCTOR DEVICE WITH BURIED BITLINE AND METHOD FOR FABRICATING THE SAME

## CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority of Korean Patent Application No. 10-2012-0094396, filed on Aug. 28, 2012, which is incorporated herein by reference in its entirety.

## BACKGROUND

### 1. Field

Exemplary embodiments of the present invention relate to a semiconductor device, and more particularly, to a semiconductor device with buried bit lines and a method for fabricating the same.

### 2. Description of the Related Art

Most semiconductor devices include transistors. For example, in a memory device such as a DRAM, a memory cell includes a cell transistor such as a MOSFET. In general, in a MOSFET, source/drain regions are formed in a semiconductor substrate, and thus, a planar channel is formed between the source region and the drain region. Such a general MOSFET is referred to as a planar channel transistor.

As improvements in the degree of integration and the performance of a memory device are continuously demanded, a technology for fabricating a MOSFET faces physical limitations. For example, as the size of a memory cell shrinks, the size of a MOSFET shrinks, as a result of which the channel length of the MOSFET cannot help but be shortened. If the channel length of a MOSFET is shortened, data retaining properties are likely to deteriorate, whereby the characteristics of the memory device may be degraded.

In consideration of these problems, a vertical channel transistor (VCT) has been suggested in the art. The vertical channel transistor includes a pillar in which a vertical channel is formed. A source region and a drain region are formed in the upper and lower portions of the pillar. Any one of the source region and the drain region is connected with a bit line.

FIG. 1 is a view illustrating a conventional semiconductor device.

Referring to FIG. 1, a plurality of body lines 12 are formed on a semiconductor substrate 11 in such a way as to be separated from one another. Pillars 13 are vertically formed on the surfaces of the body lines 12. Buried bit lines 14 are buried in the body lines 12. The pillars 13 include first and second source/drain regions 16 and 18 and channel regions 17. Word lines 15 are formed on the sidewalls of the pillars 13 to extend in a direction crossing with the buried bit lines 14. Since the word lines 15 have vertical structures, vertical channels are formed.

In the conventional art shown in FIG. 1, the body lines 12 are formed by etching the semiconductor substrate 11 in consideration of the height of the pillars 13 including the channel regions 17. Thereafter, by etching the upper parts of the body lines 12, the pillars 13 are formed.

In the conventional art, in order to prevent punch-through P from occurring between adjacent buried bit lines 14, a predetermined height P1 should be secured under the buried bit lines 14. The height P1 for preventing the punch-through P should be approximately 80 to 90 nm including the depth of the first source/drain regions 16 lying under the buried bit lines 14. Therefore, because a total height H including the

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body lines 12 and the pillars 13 increases, high aspect ratio etching is required when forming the body lines 12.

As a result, in the conventional art, not only the high aspect ratio etching is required since the height of the pillars 13 should be considered when forming the body lines 12, but also aspect ratio further increases in order to prevent the punch-through P between the buried bit lines 14. As a consequence, pattern leaning may result.

## SUMMARY

In an exemplary embodiment, a method for fabricating a semiconductor device may include: forming active regions in a semiconductor substrate, the active regions being separated by a plurality of first trenches; forming a support in each first trench of the plurality of first trenches; defining, by etching the active regions, second trenches that are shallower than the plurality of first trenches; and forming a pair of buried bit lines in each of the second trenches.

In an exemplary embodiment, a method for fabricating a semiconductor device may include: forming, on a semiconductor substrate, active regions that are separated by a plurality of first trenches; forming a support in each first trench of the plurality of first trenches; etching the active regions to define second trenches that are shallower than the plurality of first trenches; forming spacers on sidewalls of the second trenches; etching bottoms of the second trenches to define third trenches; forming punch-through preventing patterns in the third trenches; etching portions of the sidewalls that are not covered by the punch-through preventing patterns or the spacers to form facing recessed sidewalls; and forming buried bit lines in the facing recessed sidewalls.

In an exemplary embodiment, a semiconductor device may include: a plurality of active regions formed on a semiconductor substrate and separated, where the plurality of active regions are separated by first trenches; a support formed in each of the first trenches; second trenches dividing the plurality of active regions, where the second trenches have a depth that is shallower than a depth of the first trenches; and a pair of buried bit lines formed in each of the second trenches.

In an exemplary embodiment, a semiconductor device may include: a pair of body lines having recessed sidewalls that face each other; a trench extending beneath the recessed sidewalls; a punch-through preventing pattern formed in the trench; and buried bit lines formed in the recessed sidewalls.

In an exemplary embodiment, a semiconductor device may include: a plurality of active regions formed on a semiconductor substrate, where the plurality of active regions are separated by first trenches; a support formed in each first trench; second trenches dividing the plurality of active regions; a spacer formed on each sidewall of each of the second trenches; a pair of recessed sidewalls extending under each second trench; a third trench extending under the pair of recessed sidewalls; a punch-through preventing pattern formed in the third trench; and buried bit lines formed on the sidewalls.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view illustrating a conventional semiconductor device.

FIG. 2A is a view illustrating a semiconductor device with buried bit lines in accordance with an exemplary embodiment.

FIG. 2B is a view illustrating a semiconductor device with buried bit lines in accordance with an exemplary embodiment.

FIGS. 3A to 3I are views illustrating an exemplary method for forming the buried bit lines of the semiconductor device in accordance with an exemplary embodiment.

FIGS. 4A to 4J are views illustrating an exemplary method for forming the buried bit lines of the semiconductor device in accordance with an exemplary embodiment.

FIGS. 5A to 5D are views illustrating an exemplary method for forming the pillars and the word lines of the semiconductor device in accordance with an exemplary embodiment.

#### DETAILED DESCRIPTION

Various embodiments will be described below in more detail with reference to the accompanying drawings. The present invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the present invention to those skilled in the art. Throughout the disclosure, like reference numerals refer to like parts throughout the various figures and embodiments of the present invention.

The drawings are not necessarily to scale and in some instances, proportions may have been exaggerated in order to clearly illustrate features of the embodiments. When a first layer is referred to as being “on” a second layer or “on” a substrate, it not only refers to a case where the first layer is formed directly on the second layer or the substrate but also a case where a third layer exists between the first layer and the second layer or the substrate.

FIG. 2A is a view illustrating a semiconductor device with buried bit lines in accordance with an exemplary embodiment. FIG. 2B is a view illustrating a semiconductor device with buried bit lines in accordance with an exemplary embodiment.

Referring to FIGS. 2A and 2B, a semiconductor device includes buried bit lines **104**, pillars **103**, and word lines **105**. A plurality of active regions with vertical structures including semiconductor bodies **101**, body lines **102** and the pillars **103** are formed on a semiconductor substrate **100**. Supports **106** are formed between the plurality of active regions. The buried bit lines **104** are buried in the body lines **102**. The buried bit lines **104** extend in a first direction X, and the word lines **105** extend in a second direction Y. The active regions may extend in a third direction Z that is perpendicular to the first direction X and the second direction Y.

The semiconductor substrate **100** may include a silicon-containing substance, such as monocrystalline silicon. The semiconductor bodies **101**, the body lines **102**, the pillars **103**, and the semiconductor substrate **100** may include the same substance. Accordingly, the semiconductor bodies **101**, the body lines **102**, and the pillars **103** include monocrystalline silicon.

Each active region includes a semiconductor body **101**, a pair of body lines **102**, which are formed on the semiconductor body **101**, and a plurality of pillars **103** that are formed on the body lines **102**. A plurality of pillars **103** may be formed on each body line **102**. The semiconductor body **101** is formed perpendicular to the first direction X and the second direction Y on the semiconductor substrate **100**. The body lines **102** are formed perpendicular to the first direction X and the second direction Y on the semiconductor body **101**. The pillars **103** may be formed to extend perpendicular

to the first direction X and the second direction Y from the body lines **102**. For example, the body lines **102** and the pillars **103** may be orthogonal to each other. The plurality of pillars **103** are formed to be separated from one another on the body lines **102**. The plurality of pillars **103** may have the array layout of a matrix structure. The plurality of pillars **103** may include the channel regions of vertical channel transistors. Furthermore, the plurality of pillars **103** may have structures in which the source/drain regions and the channel regions of vertical channel transistors are formed.

The body lines **102** are formed perpendicular to the first direction X and the second direction Y on the semiconductor body **101**. A pair of body lines **102** may be formed on the semiconductor body **101**. The pair of body lines **102** may extend in the first direction X. The buried bit lines **104** and the pair body lines **102** may extend in the first direction X in the same manner. Although descriptions will be made later, the pair body lines **102** may be formed by dividing a line-type active region. A support **106** is formed between the pair of body lines **102**. Body lines **102** may be formed into a pair on each semiconductor body **101**. The supports **106** may be formed in trenches separating adjacent pairs of body lines **102**. The supports **106** may include a dielectric layer. The depth of the trenches is deeper than the buried bit lines **104**. Thus, it is possible to prevent the punch-through between the buried bit lines **104**, which are formed with the supports **106** therebetween. The supports **106** may extend to be formed between the pillars **103**.

The buried bit lines **104** are buried in the body lines **102**. Each body line **102** may have a recessed sidewall that is formed with the buried bit line **104**. The pair of body lines **102** that are formed on the semiconductor body **101** may face each other, and due to this fact, the recessed sidewalls may face each other. The buried bit lines **104** may extend in the first direction X. The buried bit lines **104** include a metallic substance, such as a metal or a metal silicide. As a consequence, the buried bit lines **104** have low resistance.

Interlayer dielectric layers **107** may be formed between the buried bit lines **104**. The buried bit lines **104** may have air gaps **108**. As shown in FIG. 2A, the trenches, in which the interlayer dielectric layers **107** are formed, may be deeper than the buried bit lines **104**. Therefore, it is possible to prevent the punch-through between the buried bit lines **104**, which are formed with the interlayer dielectric layers **107** interposed therebetween. As shown in FIG. 2B, punch-through preventing patterns **109** may be formed under the interlayer dielectric layers **107**. The punch-through preventing patterns **109** may include a dielectric layer. The interlayer dielectric layer **107s** may extend to be formed between the pillars **103**. When viewed in the second direction Y, the supports **106**, the pillars **103** and the Interlayer dielectric layer **107s** may be alternately formed.

The word lines **105** are formed on the sidewalls of the pillars **103**. The word lines **105** are vertically formed on the sidewalls of the pillars **103**, and thus, are referred to as vertical word lines. The word lines **105** may be formed on both sidewalls of the pillars **103** and thus, may form double word line structures. Even though the double word line structures are formed, ends of the respective word lines **105** may be connected. Since the pillars **103** serve as regions where the channels of vertical channel transistors are formed, vertical channels are formed by the word lines **105**. By this fact, vertical channel transistors, including the word lines **105**, source regions, channel regions and drain regions are formed. The word lines **105** may extend in the second direction Y that is perpendicular to the first direction X (the extending direction of the buried bit lines **104**). The word

lines **105** include a metallic substance, such as, for example, titanium nitride (TiN) or a stack of a tungsten nitride and tungsten (WN/W). The word lines **105** and the buried bit lines **104** may be separated from each other by a dielectric layer (not shown) may be additionally formed between the word lines **105** and the buried bit lines **104**. Here, the dielectric layer may include, for example, a silicon oxide. In an exemplary embodiment, the word lines **105** may extend in the second direction Y that is perpendicular to the first direction X (the extending direction of the buried bit lines **104**) while surrounding the sidewalls of the pillars **103**. Moreover, after forming gate electrodes to surround the sidewalls of the pillars **103**, the word lines **105** may be formed to be connected with the gate electrodes.

According to FIGS. 2A and 2B, vertical structures where the buried bit lines **104** are positioned are formed below the pillars **103**. As a consequence, since it is not necessary to form the buried bit lines **104** between the pillars **103**, high integration becomes possible.

The buried bit lines **104** are buried in the body lines **102**. Accordingly, adjacent buried bit lines **104** are sufficiently separated from one another, so that a parasitic capacitance ( $C_B$ ) between adjacent buried bit lines **104** may be decreased. Furthermore, because the interlayer dielectric layers **107**, having the air gaps **108**, are formed between adjacent buried bit lines **104**, the parasitic capacitance may further be decreased.

Since the supports **106** are formed between the adjacent pairs of body lines **102**, it is possible to prevent the body lines **102** and the pillars **103** from leaning.

Also, since the trenches in which the supports **106** are formed and the trenches in which the interlayer dielectric layers **107** are formed are deeper than the buried bit lines **104**, the punch-through between adjacent buried bit lines **104** may be prevented. Furthermore, since the punch-through preventing patterns **109** are formed under the interlayer dielectric layers **107**, the punch-through between adjacent buried bit lines **104** may be further prevented.

FIGS. 3A to 3I are views illustrating an exemplary method for forming the buried bit lines of the semiconductor device in accordance with an exemplary embodiment.

Referring to FIG. 3A, first mask patterns **22A** are formed on a semiconductor substrate **21**. The semiconductor substrate **21** may include a monocrystalline substance, such as monocrystalline silicon. The first mask patterns **22A** include a silicon nitride. The first mask patterns **22A** may be a stack structure that includes a silicon oxide and a silicon nitride. For example, the first mask patterns **22A** may be deposited in order of a silicon nitride and a silicon oxide. Furthermore, the first mask patterns **22A** may be deposited in order of a silicon nitride, a silicon oxide, a silicon oxynitride, or an amorphous carbon. In the case where the silicon nitride is included, a pad oxide layer (not shown) may be additionally formed between the semiconductor substrate **21** and the first mask patterns **22A**. The first mask patterns **22A** may be formed using unillustrated photoresist patterns. The first mask patterns **22A** are formed to extend in the first direction. The first mask patterns **22A** may include line patterns that extend in the first direction X.

Next, the semiconductor substrate **21** is etched using the first mask patterns **22A** as etch masks to define a plurality of first trenches **23** having a predetermined depth when measured from the upper surface of the semiconductor substrate **21**. The first trenches **23** may extend in the first direction X. The first trenches **23** divide the semiconductor substrate **21** into a plurality of active regions **24A**. Each active region **24A**, of the plurality of active regions **24A**, has a pair of

sidewalls. An etching process for defining the first trenches **23** may include anisotropic etching. When viewed on the top, the active regions **24A** are separated by the first trenches **23** and have line-type shapes that extend in the first direction X. Also, the active regions **24A** are formed perpendicular to the first direction X and the second direction Y on the semiconductor substrate **21**.

As described above, the plurality of active regions **24A** are separated from one another by the first trenches **23**. The plurality of active regions **24A** each have a first width W1. Since the first width W1 has a substantially large dimension based on two body lines and a space defined therebetween, it is possible to prevent the active regions **24A** from leaning when defining the first trenches **23**. The first trenches **23** have a first depth D1.

Referring to FIG. 3B, a liner layer **25** may be formed on the sidewalls of the active regions **24A** that define the sidewalls of a first trench **23** to fill the first trench **23**. The liner layer **25** may include a nitride, such as a silicon nitride. A support **26** is then formed in the first trench **23**, on the liner layer **25**, to fill the first trench. The support **26** may include an oxide, such as a silicon oxide. The support **26** may include a substance with a low dielectric constant, so that a parasitic capacitance between buried bit lines (that will be subsequently formed) may be decreased. In order to form the support **26**, a planarization process, such as etch-back or CMP (chemical mechanical polishing), may be performed after the first trench is formed **23**.

The support **26** has is formed between adjacent active regions **24A** of the plurality of active regions **24A**. Thus, pattern leaning may be prevented when subsequently performing an etching process on the adjacent active regions **24A**. Also, the support **26** may serve as a separation layer that separates adjacent active regions **24A** from each other.

Referring to FIG. 3C, second mask patterns **27** are formed on the supports **26** and the first mask patterns **22A**. The second mask patterns **27** may include line patterns that extend in the first direction X. Portions of the first mask patterns **22A** are exposed through line-type spaces that are defined between adjacent second mask patterns **27**. Middle portions of the respective first mask patterns **22A** may be exposed through the spaces between the second mask patterns **27**.

In this way, the second mask patterns **27** cover at least the upper ends of the supports **26** and have the line-type spaces that are patterned to expose the middle portions of the first mask patterns **22A**.

The second mask patterns **27** may be formed of a substance that may provide an etching selectivity with respect to the first mask patterns **22A**, such as amorphous carbon. A photolithography process may be employed to form the second mask patterns **27**.

The exposed first mask patterns **22A** and active regions **24A** that lie under the first mask patterns **22A** are etched using the second mask patterns **27** as etch masks to define a plurality of preliminary second trenches **28**. The respective preliminary second trenches **28** are defined between adjacent first trenches **23**. An upper portion of an active region **24A** is divided by a preliminary second trench **28**. An active region divided by the preliminary second trench **28** is designated by the reference numeral **24B**. A first mask pattern **22** may remain on the active region **24B**. The preliminary second trench **28** has a second width W2. The second width W2 may correspond to  $\frac{1}{3}$  of the first width W1. The preliminary second trench **28** has a second depth D2 that may be smaller than the first depth D1 of the first trench **23**.

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Since the active region **24B** is supported by the support **26**, pattern leaning does not occur when defining the preliminary second trench **28**.

Referring to FIG. 3D, spacers **29** are formed on sidewalls of the active region **24B** that defines the sidewalls of the preliminary second trench **28**. The spacers **29** may include a nitride, such as a silicon nitride. In order to form the spacers **29**, the nitride may be conformally formed, and then, etch-back may be performed. The spacers **29** cover the sidewalls of the preliminary second trench **28** and cover the sidewalls of the first mask pattern **22** and the second mask pattern **27**. In an etch-back process for forming the spacers **29**, a surface of the active region **24B** that defines a bottom **28A** of the preliminary second trench **28** may be recessed by a preselected depth, so that subsequent isotropic etching may be easily performed.

Referring to FIG. 3E, isotropic etching is performed using the spacers **29** and the first mask pattern **22** and the second mask pattern **27** as etch barriers. Therefore, the bottom of the preliminary second trench **28** is selectively etched to form recessed sidewalls **30**. Therefore, a bulb-type trench structures that includes the preliminary second trench **28** and the recessed sidewalls **30** is formed. By defining a plurality of bulb-type second trenches **301** and **302**, a plurality of body lines **241**, **242**, **243** and **244** are formed. Etch amounts on the lower sidewalls of the respective body lines **241**, **242**, **243** and **244** may be controlled.

Each bulb-type second trench **301** and **302** is formed between a corresponding pair of adjacent first trenches **23**. Therefore, the plurality of body lines **241**, **242**, **243**, and **244** are separated from one another by the bulb-type second trenches **301** and **302**. For example, the first body line **241** and the second body line **242** are separated by the bulb-type second trench **301**, and the third body line **243** and the fourth body line **244** are separated by the bulb-type second trench **302**. Therefore, the first body line **241** and the second body line **242**, separated by the first bulb-type trench **301**, are considered to be a first body line pair. Similarly, the third body line **243** and the fourth body line **244**, separated by the second bulb-type trench **302**, are considered to be a second body line pair. The first body line pair and the second body line pair may be separated from each other by the support **26**. In another embodiment, another body line pair may be formed with the support **26** interposed between two body lines. For instance, the first body line **241** and the fourth body line **244** may form a pair.

The first bulb-type second trench **301** and the second bulb-type second trench **302** have a third depth **D3**. The third depth **D3** is controlled to be smaller than the first depth **D1** of the first trench **23**, in which the supports **26** is formed. The respective body lines **241**, **242**, **243** and **244** each have a height **H1** that is substantially the same as the third depth **D3**. The respective body lines **241**, **242**, **243** and **244** each have the same width. Even though the third depth **D3** of the first bulb-type second trench **301** and the second bulb-type second trench **302** is deep, the body lines **241**, **242**, **243** and **244** are prevented from leaning, due to the presence of the supports **26**. When viewed on the top, the plurality of body lines **241**, **242**, **243** and **244** are separated from one another by the first bulb-type second trench **301** and the second bulb-type second trench **302** and extend in the first direction. The sidewalls of the body lines **241**, **242**, **243** and **244** are recessed by the first bulb-type second trench **301** and the second bulb-type second trench **302**, respectively. The recessed sidewalls **30** are formed on the sidewalls of the respective body lines **241**, **242**, **243** and **244**. The respective body lines **241**, **242**, **243** and **244** have first sidewalls and

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second sidewalls. The first sidewalls are formed perpendicular to the first direction **X** and the second direction **Y**, and the second sidewalls are the recessed sidewalls **30**. The recessed sidewalls **30** of each of the respective body lines **241**, **242**, **243** and **244** face each other. The first mask patterns **22** and the second mask patterns **27** remain on the body lines **241**, **242**, **243** and **244**. The spacers **29** remain on the sidewalls of the body lines **241**, **242**, **243** and **244**. The recessed sidewalls **30** may be un-protected (i.e., not protected by the spacers **29**.) Thus, the recessed sidewalls **30** may be referred to as un-protected recessed sidewalls **30**.

According to the series of processes described above, each of the active regions **24A** is divided, and the plurality of body lines **241**, **242**, **243** and **244**, which are separated by the first bulb-type second trench **301** and the second bulb-type second trench **302**, respectively, are formed. The respective body lines **241**, **242**, **243** and **244** have the recessed sidewalls **30**. The recessed sidewalls may be formed over lower sidewalls of the respective body lines **241**, **242**, **243** and **244**. Upper sidewalls of the body lines **241**, **242**, **243** and **244** are protected by the spacers **29**. The heights of the upper sidewalls and the heights of the lower sidewalls of the body lines **241**, **242**, **243** and **244** may be controlled based on a height of the spacers **29**. Semiconductor bodies **240**, having a predetermined height **H2**, may remain under the body lines **241**, **242**, **243** and **244**. The semiconductor bodies **240** are formed on the semiconductor substrate **21**. The body lines **241**, **242**, **243** and **244** are formed perpendicular to the first direction **X** and the second direction **Y** on the semiconductor bodies **240**. Two body lines may be formed on each semiconductor body **240**. Adjacent semiconductor bodies **240** are separated from each other by the first trenches **23**, and the supports **26** are formed in the first trenches **23**.

Referring to FIG. 3F, the first bulb-type second trench **301** and the second bulb-type second trench **302** are formed with a conductive layer **31A**, so that voids **32** are created in the bulbs of the first bulb-type second trench **301** and the second bulb-type second trench **302**.

The conductive layer **31A** may include a metal, such as a near-noble metal or a refractory metal. For example, the conductive layer **31A** may include cobalt (Co), titanium (Ti), tantalum (Ta), nickel (Ni), tungsten (W), platinum (Pt), or palladium (Pd). The conductive layer **31A** may be formed through chemical vapor deposition (CVD) or atomic layer deposition (ALD). The deposition depth of the conductive layer **31A** may be controlled to be a thickness that covers at least the un-protected recessed sidewalls **30**.

Before forming the conductive layer **31A**, source/drain regions (not shown) may be formed. The source/drain regions may be formed using plasma doping, tilt ion implantation, etc. For example, with the plasma doping, is possible to form the source/drain regions without experiencing a shadow effect by a surrounding structure. Thus, the source/drain regions may be formed at desired positions. The source/drain regions may be formed on the surfaces of the unprotected recessed sidewalls **30**. Alternatively, in situ doped polysilicon may be used to form the source/drain regions. For example, by filling and then annealing of the doped polysilicon, the dopant in the doped polysilicon may be diffused into the body lines **241**, **242**, **243**, and **244**.

Referring to FIG. 3G, the conductive layer **31A** is planarized and etched back. Thus, conductive layer patterns **31B** are formed to partially fill the first bulb-type second trench **301** and the second bulb-type second trench **302**.

Referring to FIG. 3H, a plurality of buried bit lines **311**, **312**, **313** and **314** are formed by selectively etching the

conductive layer patterns 31B. The conductive layer patterns 31B may be etched through etch-back, so that the bulbs of the first bulb-type second trench 301 and the second bulb-type second trench 302 define the shape of the surfaces of the buried bit lines 311, 312, 313, and 314.

The buried bit lines 311, 312, 313 and 314 may be separately formed in the first bulb-type second trench 301 and the second bulb-type second trench 302. Because the unprotected recessed sidewalls 30 of the first bulb-type second trench 301 and the second bulb-type second trench 302 have structures corresponding to the recessed sidewalls 30 of the body lines 241, 242, 243 and 244, the buried bit lines 311, 312, 313 and 314 may have structures that are formed in the recessed sidewalls 30 of the body lines 241, 242, 243 and 244. For instance, the first buried bit line 311 and the second buried bit line 312 may be separately formed in first bulb-type second trench 301, and the third buried bit line 313 and the fourth buried bit line 314 may be separately formed in second bulb-type second trench 302. The first buried bit line 311 and the fourth buried bit line 314 may be separated by the support 26. Thus, the first buried bit line 311 and the fourth buried bit line 314 may form a pair of buried bit lines. By recessing the bottoms of the first bulb-type second trench 301 and the second bulb-type second trench 302 by a predefined depth, punch-through preventing patterns 34 may be formed. By forming the punch-through preventing patterns 34, punch-through between the first buried bit line 311 and the second buried bit line 312 and punch-through between the third buried bit line 313 and the fourth buried bit line 314 may be prevented. The depth of the punch-through preventing patterns 34 is shallower than the depth of the first trenches 23. Accordingly, pattern leaning is prevented.

The plurality of buried bit lines 311, 312, 313, and 314 may form other pairs of buried bit lines with the supports 26 formed between two adjacent buried bit lines. For example, as previously discussed, the first buried bit line 311 and the fourth buried bit line 314 may form a pair of buried bit lines having the support 26 interposed therebetween. Since the depth of the first trench 23 is deep, punch-through between the first buried bit line 311 and the fourth buried bit line 314 is prevented.

Referring to FIG. 3I, of the first bulb-type second trench 301 and the second bulb-type second trench 302 are formed with an interlayer dielectric layer 35. The interlayer dielectric layer 35 may include an oxide, such as BPSG (boron phosphorus silicate glass). The interlayer dielectric layer 35 is formed so that air gaps 36 are defined. The interlayer dielectric layer 35 may include a first interlayer dielectric layer 35A and a second interlayer dielectric layer 35B. For example, after lining first bulb-type second trench 301 and the second bulb-type second trench 302 with the first interlayer dielectric layer 35A, the first bulb-type second trench 301 and the second bulb-type second trench 302 may be formed using the second interlayer dielectric layer 35B. Since the spaces of the first bulb-type second trench 301 and the second bulb-type second trench 302 are very narrow after forming the first interlayer dielectric layer 35A, the bulb portions of the first bulb-type second trench 301 and the second bulb-type second trench 302 are not formed when forming the second interlayer dielectric layer 35B. Thus, the air gaps 36 may be defined. Alternatively, the interlayer dielectric layer 35 may be formed using a method with poor step coverage to define the air gaps 36.

Subsequently, the interlayer dielectric layer 35 may be planarized such that the surfaces of the second mask patterns 27 are exposed.

The first buried bit line 311 and the second buried bit line 312 are isolated from each other by the interlayer dielectric layer 35. Likewise, the third buried bit line 313 and the fourth buried bit line 314 are isolated from each other by the interlayer dielectric layer 35. Furthermore, due to the presence of the air gaps 36, the parasitic capacitance between the first buried bit line 311 and the second buried bit line 312, and the parasitic capacitance between the third buried bit line 313 and the fourth buried bit line 314 may be significantly decreased.

According to an exemplary implementation, the buried bit lines 311, 312, 313 and 314 are formed in the un-protected recessed sidewalls 30 of the body lines 241, 242, 243 and 244, which are separated by the first bulb-type second trench 301 and the second bulb-type second trench 302. Moreover, adjacent pairs of buried bit lines 311, 312, 313 and 314 may be formed in the first bulb-type second trench 301 and the second bulb-type second trench 302, respectively. Therefore, adjacent buried bit lines 311/312 and 313/314 are sufficiently separated from each other by the first bulb-type second trench 301 and the second bulb-type second trench 302, respectively. Accordingly, the parasitic capacitance ( $C_B$ ) between the adjacent buried bit lines 311/312 and 313/314 is decreased. Also, since the air gaps 36 are defined between the adjacent buried bit lines 311/312 and 313/314, the parasitic capacitance is further decreased.

Since the support 26 is formed between the buried bit lines 311 and 314, the punch-through between the buried bit lines 311 and 314 is prevented. In addition, because the depth of the first trench 23, in which the support 26 is formed, is larger than the depth of the second trenches 301 and 302, in which the buried bit lines 311 and 314 are formed, the punch-through between the buried bit lines 311 and 314 may be prevented. Due to the presence of the punch-through preventing patterns 34, it is possible to prevent the punch-through between the adjacent pairs of buried bit lines 311/312 and 313/314.

The body lines 241, 242, 243 and 244 are supported by the supports 26. Thus, it is possible to form the body lines 241, 242, 243 and 244 that have improved stability.

Vertical channel transistors including pillars may be formed on the body lines 241, 242, 243 and 244. In an exemplary implementation, the pillars may be formed by etching portions of the body lines 241, 242, 243 and 244. This will be described later with reference to FIGS. 5A to 5D.

FIGS. 4A to 4J are views illustrating an exemplary method for forming the buried bit lines of an exemplary semiconductor device.

Referring to FIG. 4A, first mask patterns 42A are formed on a semiconductor substrate 41. The semiconductor substrate 41 includes a monocrystalline substance, such as monocrystalline silicon. The first mask patterns 42A include a silicon nitride. The first mask patterns 42A may be a stack structure that includes a silicon oxide and a silicon nitride. For example, the first mask patterns 42A may be deposited in order of a silicon nitride and a silicon oxide. Furthermore, the first mask patterns 42A may be deposited in order of a silicon nitride, a silicon oxide, a silicon oxynitride, or amorphous carbon. In the case where the silicon nitride is included, a pad oxide layer (not shown) may be additionally formed between the semiconductor substrate 41 and the first mask patterns 42A. The first mask patterns 42A may be formed using unillustrated photoresist patterns. The first mask patterns 42A are formed to extend in the first direction X. The first mask patterns 42A may include line patterns that extend in the first direction X.

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Next, the semiconductor substrate **41** is etched using the first mask patterns **42A** as etch masks to define a plurality of first trenches having a predetermined depth when measured from the upper surface of the semiconductor substrate **41**. The first trenches **43** may extend in the first direction X. The first trenches **43** divide the semiconductor substrate **41** into a plurality of active regions **44A**. Each active region **44A**, of the plurality of active regions **44A**, has a pair of sidewalls. An etching process for defining the first trenches **43** may include anisotropic etching. When viewed on the top, the active regions **44A** are separated by the first trenches **43** and have line-type shapes that extend in the first direction X. Also, the active regions **44A** are formed perpendicular to the first direction X and the second direction Y on the semiconductor substrate **41**.

As described above, the plurality of active regions **44A** are separated from one another by the first trenches **43**. The plurality of active regions **44A** each have a first width **W1**. Since the first width **W1** has a substantially large dimension based on two body lines and a space defined therebetween, it is possible to prevent the active regions **44A** from leaning when defining the first trenches **43**. The first trenches **43** have a first depth **D1**.

Referring to FIG. 4B, a liner layer **45** may be formed on the sidewalls of the active regions **44A** that define the sidewalls of a first trench **43** to fill the first trench **43**. The liner layer **45** may include a nitride, such as a silicon nitride. A support **46** is then formed in the first trench **43**, on the liner layer **45**, to fill the first trench. The support **46** may include an oxide, such as a silicon oxide. The support **46** may include a substance with a low dielectric constant, so that a parasitic capacitance between buried bit lines (that will be subsequently formed) may be decreased. In order to form the support **46**, a planarization process, such as etch-back or CMP (chemical mechanical polishing), may be performed after the first trench **43** is formed.

The support **46** is formed between adjacent active regions **44A**. Thus, pattern leaning may be prevented when subsequently performing an etching process on the adjacent active regions **44A**. Also, the support **46** may serve as a separation layer that separates adjacent active regions **44A**.

Referring to FIG. 4C, second mask patterns **47** are formed on the supports **46** and the first mask patterns **42A**. The second mask patterns **47** may include line patterns that extend in the first direction X. Portions of the first mask patterns **42A** are exposed through line type spaces that are defined between adjacent second mask patterns **47**. Middle portions of the respective first mask patterns **42A** may be exposed through the spaces between the second mask patterns **47**.

In this way, the second mask patterns **47** cover at least the upper ends of the supports **46** and have the line-type spaces that are patterned to expose the middle portions of the first mask patterns **42A**.

The second mask patterns **47** may be formed of a substance that may provide an etching selectivity with respect to the first mask patterns **42A**, such as amorphous carbon. A photolithography process may be employed to form the second mask patterns **47**.

The exposed first mask patterns **42A** and the active regions **44A** that lie under the first mask patterns **42A** are etched using the second mask patterns **47** as etch masks to define a plurality of second trenches **48**. The respective second trenches **48** are defined between adjacent first trenches **43**. An upper portion of an active region **44A** is divided by a second trench **48**. An active region divided by the second trench is designated by the reference numeral

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**44B**. A first mask pattern **42** may remain on the active regions **448**. The second trench **48** has a second width **W2**. The second width **W2** may correspond to  $\frac{1}{3}$  of the first width **W1**. The second trench **48** has a depth that may be smaller than the first depth **D1** of the first trench **43**.

Since the active region **44B** is supported by the support **46**, pattern leaning does not occur when defining the second trench **48**.

Referring to FIG. 4D, spacers **49** are formed on the sidewalls of the active region **44B** that defines the sidewalls of the second trenches **48**. The spacers **49** may include a nitride, such as a silicon nitride. In order to form the spacers **49**, the nitride may be conformally formed, and then, etch-back may be performed. The spacers **49** cover the sidewalls of the second trench **48** and cover the sidewalls of the first mask pattern **42** and second mask pattern **47**.

The active region **44B** is etched using the spacers **49**, and the first mask pattern **42**, and second mask pattern **47** as etch barriers. Thus, a surface of the active region **44B** that defines a bottom **48A** of the second trench **48** is selectively etched to define a third trench **50**. An active region having the third trench **50** is designated by the reference numeral **44C**. The second trench **48** and the third trench **50** form integral trench structures. The total depth of the third trench **50** and the second trench **48** is defined as a second depth **D2**. The second depth **D2** is set to be smaller than the first depth **D1** of the first trench **43**.

Referring to FIG. 4E, punch-through preventing patterns **51** that partially fill the third trenches **50** are formed. The punch-through preventing patterns **51** may include an oxide such as a silicon oxide. Furthermore, the punch-through preventing patterns **51** may include a nitride such as a silicon nitride. The punch-through preventing patterns **51** may serve as etch barriers in a subsequent isotropic etching process.

Referring to FIG. 4F, isotropic etching is performed using the spacers **49** and the first and second mask patterns **42** and **47** as etch barriers. According to this fact, both sidewalls of the third trenches **50**, which are not protected by the spacers **49** and the punch-through preventing patterns **51**, are selectively etched, and recessed sidewalls **52** are formed. By the recessed sidewalls **52**, a plurality of body lines **441**, **442**, **443** and **444** are formed. As a result, the plurality of body lines **441**, **442**, **443** and **444** are separated from one another by fourth trenches **520** and **521** including the recessed sidewalls **52**. The fourth trenches **520** and **521** have bulb-type trench structures including the second trenches **48** and the recessed sidewalls **52**.

By such isotropic etching, the fourth trenches **520** and **521** may become bulb-type trenches. Therefore, the lower portions of the fourth trenches **520** and **521** may have curvatures. Etch amounts on the lower sidewalls of the respective body lines **441**, **442**, **443** and **444** may be controlled. The depth of the fourth trenches **520** and **521** may be limited by the punch-through preventing patterns **51**.

The bulb-type fourth trenches **520** and **521** are defined between two adjacent first trenches **43**. The plurality of body lines **441**, **442**, **443** and **444** are separated from one another by the fourth trenches **520** and **521**. For example, the first body line **441** and the second body line **442** are separated by the fourth trench **520**, and the third body line **443** and the fourth body line **444** are separated by the fourth trench **521**. As a consequence, as the first body line **441** and the second body line **442** are paired by the fourth trench **520**, a first body line pair is formed. Also, as the third body line **443** and the fourth body line **444** are paired by the fourth trench **521**, a second body line pair is formed. The first body line pair and the second body line pair may be separated from each

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other by the support 46. Another body line pair may be formed with the support 46 interposed between two body lines. For instance, the first body line 441 and the fourth body line 444 may form a pair.

The fourth trenches 520 and 521 have a third depth D3. The third depth D3 is controlled to be smaller than the first depth D1 of the first trenches 43 in which the supports 46 are formed. The respective body lines 441, 442, 443 and 444 have a height H1 that is identical to the third depth D3. The respective body lines 441, 442, 443 and 444 have the same width. Even though the third depth D3 of the fourth trenches 520 and 521 is substantial, the body lines 441, 442, 443 and 444 are prevented from leaning, due to the presence of the supports 46. When viewed on the top, the plurality of body lines 441, 442, 443 and 444 are separated from one another by the fourth trenches 520 and 521 and extend in the first direction. The sidewalls of the body lines 441, 442, 443 and 444 are recessed by the fourth trenches 520 and 521. In other words, since the fourth trenches 520 and 521 are bulb-type trenches, the body lines 441, 442, 443 and 444 have the recessed sidewalls 52 according to the shapes of bulbs. The recessed sidewalls 52 are formed on any one sidewalls of the respective body lines 441, 442, 443 and 444. The respective body lines 441, 442, 443 and 444 have first sidewalls and second sidewalls. The first sidewalls are formed perpendicular to the first direction X and the second direction Y, and the second sidewalls are the recessed sidewalls 52. The recessed sidewalls 52 of the body lines that form a pair face each other. The first mask patterns 42 and the second mask patterns 47 remain on the body lines 441, 442, 443 and 444. The spacers 49 remain on the sidewalls of the body lines 441, 442, 443 and 444. The recessed sidewalls 52 may be non-protected sidewalls that are not protected by the spacers 49. Thus, the recessed sidewalls 52 may be referred to as recessed non-protected sidewalls.

According to the series of processes described above, each of the active regions 44A is divided into two, and the plurality of body lines 441, 442, 443 and 444 that are separated by the fourth trenches 520 and 521 are formed. The respective body lines 441, 442, 443 and 444 have the recessed sidewalls 52. The recessed sidewalls 52 may be the sidewalls of the body lines 441, 442, 443 and 444. The upper sidewalls of the body lines 441, 442, 443 and 444 are protected by the spacers 49. According to the height of the spacers 49, the heights of the upper sidewalls and the lower sidewalls of the body lines 441, 442, 443 and 444 may be controlled. The lower sidewalls of the body lines 441, 442, 443 and 444 mean the non-protected sidewalls that are exposed out of the spacers 49. Semiconductor bodies 440 with a predetermined height H2 may remain under the body lines 441, 442, 443 and 444. The semiconductor bodies 440 are formed on the semiconductor substrate 41. The body lines 441, 442, 443 and 444 are formed perpendicular to the first direction X and the second direction Y on the semiconductor bodies 440. Two body lines may be formed on each semiconductor body 440. Adjacent semiconductor bodies 440 are separated from each other by the first trenches 43, and the supports 46 are formed in the first trenches 43.

Referring to FIG. 4G, a conductive layer 53A is formed on the entire surface to gapfill the fourth trenches 520 and 521. The conductive layer 53A may include a metal such as a near-noble metal and a refractory metal. For example, the conductive layer 53A includes any one selected among cobalt (Co), titanium (Ti), tantalum (Ta), nickel (Ni), tungsten (W), platinum (Pt) and palladium (Pd). The conductive layer 53A is formed through chemical vapor deposition (CVD) or atomic layer deposition (ALD). The deposition

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depth of the conductive layer 53A may be controlled to be a thickness that covers at least the recessed sidewalls 52.

When forming the conductive layer 53A as described above, voids 54 may be created. The voids 54 may be created in the bulbs of the fourth trenches 520 and 521 adjacent to the recessed sidewalls 52.

Meanwhile, before forming the conductive layer 53A, source/drain regions (not shown) may be formed. The source/drain regions may be formed using plasma doping, tilt ion implantation, etc. In particular, the plasma doping is possible without experiencing a shadow effect by a surrounding structure. Due to this fact, the source/drain regions may be formed at desired positions. The source/drain regions may be formed on the surfaces of the recessed sidewalls 52. In another method for forming the source/drain regions, doped polysilicon doped in situ with a dopant may be used. For example, by gapfilling and then annealing doped polysilicon, the dopant in the doped polysilicon may be diffused.

Referring to FIG. 4H, the conductive layer 53A is planarized and etched back. According to this fact, conductive layer patterns 53B are formed to partially fill the fourth trenches 520 and 521.

Referring to FIG. 4I, by selectively etching the conductive layer patterns 53B, a plurality of buried bit lines 531, 532, 533 and 534 are formed. The conductive layer patterns 53B may be etched through etch-back.

The buried bit lines 531, 532, 533 and 534 may have structures that are formed in the recessed sidewalls 52 of the body lines 441, 442, 443 and 444. The buried bit lines 531, 532, 533 and 534 may be formed in the fourth trenches 520 and 521. Moreover, the buried bit lines 531, 532, 533 and 534 may be formed by being formed into the recessed sidewalls 52 of the body lines 441, 442, 443 and 444. The pair of buried bit lines 531 and 532 are separately formed in the fourth trench 520, and the pair of buried bit line 533 and 534 are separately formed in the fourth trench 521.

The pairs of buried bit lines 531/532 and 533/534 are sufficiently isolated from each other by the punch-through preventing patterns 51. In this way, punch-through between the buried bit lines 531/532 and 533/534 may be prevented by the punch-through preventing patterns 51. The shapes of the voids 54 may be transcribed as the surfaces of the buried bit lines 531, 532, 533 and 534.

The plurality of buried bit lines 531, 532, 533 and 534 may form other pairs with the supports 46 interposed between two adjacent buried bit lines. For example, the buried bit lines 531/534 may form another pair with the support 46 interposed therebetween. Since the depth of the first trenches 43 is substantial, punch-through between the buried bit lines 531/534 is prevented.

Referring to FIG. 4J, an interlayer dielectric layer 55 is formed in the fourth trenches 520 and 521. The interlayer dielectric layer 55 may include an oxide such as BPSG (boron phosphorus silicate glass). When the interlayer dielectric layer 55 is formed, air gaps 56 may be defined between the pairs of buried bit lines 531/532 and 533/534. The interlayer dielectric layer 55 may include a first interlayer dielectric layer 55A and a second interlayer dielectric layer 55B. For example, after lining the first interlayer dielectric layer 55A, the fourth trenches 520 and 521 may be formed using the second interlayer dielectric layer 55B. Since the spaces of the fourth trenches 520 and 521 are very narrow, the lower portions of the fourth trenches 520 and 521 are not formed when forming the second interlayer dielectric layer 55B. According to this fact, the air gaps 56



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may be defined. In another embodiment, in order to define the air gaps 56, the interlayer dielectric layer 55 may be formed using a method with poor step coverage.

Subsequently, the interlayer dielectric layer 55 may be planarized such that the surfaces of the second mask patterns 47 are exposed.

By the interlayer dielectric layer 55, the pairs of buried bit lines 531/532 and 533/534 are isolated from each other. Furthermore, due to the presence of the air gaps 56, the parasitic capacitance between the pairs of buried bit lines 531/532 and 533/534 may be significantly decreased.

According to the present embodiment, the buried bit lines 531, 532, 533 and 534 are formed in the body lines 441, 442, 443 and 444 that are separated by the fourth trenches 520 and 521. Moreover, the buried bit lines 531, 532, 533 and 534 may be formed in the fourth trenches 520 and 521 to define structures that form pairs. Therefore, adjacent buried bit lines 531/532 and 533/534 are sufficiently separated from each other by the fourth trenches 520 and 521, and the parasitic capacitance ( $C_B$ ) between the adjacent buried bit lines 531/532 and 533/534 is decreased. Also, since the air gaps 56 are defined between the adjacent buried bit lines 531/532 and 533/534, the parasitic capacitance is further decreased.

Since the support 46 is formed between the buried bit lines 531 and 534, the punch-through between the buried bit lines 531 and 534 is prevented. In addition, because the depth of the first trench 43 in which the support 46 is formed is larger than the depth of the fourth trenches 520 and 521 in which the buried bit lines 531 and 534 are formed, the punch-through between the buried bit lines 531 and 534 may be further prevented.

The body lines 441, 442, 443 and 444 are firmly supported by the supports 46. Thus, it is possible to form the body lines 441, 442, 443 and 444 that are structurally stable.

Vertical channel transistors including pillars may be formed on the body lines 441, 442, 443 and 444. In the present embodiment, by etching portions of the body lines 441, 442, 443 and 444, the pillars may be formed. A method for forming pillars, vertical channel transistors, word lines and capacitors will be described below in the following embodiment.

FIGS. 5A to 5D are views illustrating an exemplary method for forming the pillars and the word lines of the semiconductor device in accordance with the first embodiment. The method described below is according to the line A-A' of FIG. 3I.

Referring to FIG. 5A, third trenches 62 are defined. The third trenches 62 are defined by etching portions of the body line 241. In order to define the third trenches 62, third mask patterns 61 may be used. The third mask patterns 61 may include line patterns that extend in the direction crossing with the body line 241. Using the third mask patterns 61 as etch masks, the second mask patterns 27 and the first mask patterns 22 are etched, and in succession, the body line 241 is etched by a predetermined depth. According to this fact, the third trenches 62 are defined, and a plurality of pillars 2400 are formed to be separated by the third trenches 62. The bottoms of the third trenches 62 may have a depth that does not expose the buried bit line 311.

In this way, the pillars 2400 are formed by etching the body line 241, and a body line 241A remains under the pillars 2400. The body line 241A and the pillars 2400 become active regions. The buried bit line 311 is formed in the body line 241A. The semiconductor body 440 is formed between the buried bit line 311 and the semiconductor substrate 21. The body line 241A has the type of a line that

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extends in the same direction as the buried bit line 311. The pillars 2400 have shapes that extend perpendicular to the first direction X and the second direction Y on the body line 241A. The pillars 2400 are formed by the unit of cell. Accordingly, the plurality of pillars 2400 are formed on one body line 241A and are separated from one another by the third trenches 62. The third trenches 62 may have a depth that does not expose the buried bit line 311. The pillars 2400 have structures in which the source/drain regions and the channel regions of vertical channel transistors are formed. The plurality of pillars 2400 may have the array layout of a matrix structure on the body line 241A. The pillars 2400 may include silicon pillars. The pillars 2400 may include monocrystalline silicon pillars.

Referring to FIG. 5B, after removing the third mask patterns 61, a third conductive layer 64 is formed to partially gapfill the third trenches 62. A gate dielectric layer 63 may be formed before forming the third conductive layer 64. The gate dielectric layer 63 may be formed by oxidating the sidewalls of the pillars 2400 and the upper surfaces of the body line 241A. The third conductive layer 64 is formed using a low resistance substance. For example, a metallic layer may be used. The metallic layer may include a titanium layer, a titanium nitride layer, a tungsten layer, etc. The third conductive layer 64 may be recessed by sequentially performing planarization and etch-back.

Referring to FIG. 5C, by performing etch-back after depositing a dielectric layer, spacers 65 are formed. The spacers 65 may include a nitride layer.

The third conductive layer 64 is etched using the spacers 65 as etch barriers. According to this fact, word lines 64A are formed on the sidewalls of the pillars 2400. The word lines 64A may be formed in the second direction crossing with the buried bit line 311. The word lines 64A also serve as vertical gate electrodes. In another embodiment, word lines 64A may be formed to surround the pillars 2400. In still another embodiment, after forming annular vertical gate electrodes that surround the pillars 2400, word lines 64A may be formed to connect the vertical gate electrodes with one another. In further still another embodiment, after forming vertical gate electrodes, word lines 64A may be formed over the pillars 2400 to be connected with the vertical gate electrodes through gate contacts.

Referring to FIG. 5D, an interlayer dielectric layer 66 is formed to isolate the word lines 64A from one another.

By selectively removing the first mask patterns 22 and the second mask patterns 27, contact holes are defined on the pillars 2400. By performing ion implantation for the surfaces of the pillars 2400 under the contact holes, source/drain regions (not shown) are formed. Then, storage node contact plugs 67 are formed to fill the contact holes.

Storage nodes 68 of capacitors may be formed on the storage node contact plugs 67. The storage nodes 68 may have pillar-like shapes. In another embodiment, the storage nodes 68 may have cylinder shapes or concave shapes. Subsequently, a dielectric layer and top electrodes may be formed on the storage nodes 68.

As is apparent from the above descriptions, according to the various embodiments, since body lines are formed after forming supports, the aspect ratio of the body lines may be decreased, and according to this fact, it is possible to prevent the body lines from leaning.

Further, according to the various embodiments, by forming the supports and punch-through preventing patterns between adjacent buried bit lines, it is possible to prevent punch-through from occurring between the adjacent buried bit lines.

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While the present invention has been described with respect to the specific embodiments, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A method for fabricating a semiconductor device, the method comprising:

forming active regions on a semiconductor substrate, the active regions being separated by a plurality of first trenches;

forming a support in each first trench of the plurality of first trenches;

defining, by etching the active regions, second trenches that are shallower than the plurality of first trenches;

forming a pair of buried bit lines in each of the second trenches;

forming a first interlayer dielectric layer on bottom and sidewalls of the second trenches; and

forming a second interlayer dielectric layer on the first interlayer dielectric layer, to form an air gap between adjacent the buried bit lines,

wherein the second interlayer dielectric layer is filled over the air gap in a top portion of the second trenches.

2. The method of claim 1, wherein forming the supports comprises:

forming a dielectric layer on an entire surface to gapfill the first trenches; and

planarizing the dielectric layers.

3. The method of claim 1, wherein defining the second trenches comprises:

defining second trenches to divide each of the active regions;

forming spacers on sidewalls of the second trenches; and

etching bottoms of the second trenches; and

forming recessed sidewalls in each of the active regions.

4. The method of claim 3, wherein forming the pair of buried bit lines comprises:

forming a conductive layer on a surface defining the second trenches; and

etching the conductive layer so that the conductive layer remains on the recessed sidewalls in each of the active regions.

5. The method of claim 4, wherein, after etching the conductive layer, the method further comprises:

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recessing bottoms of the second trenches, between pairs of the buried bit lines, to form punch-through preventing patterns.

6. A method for fabricating a semiconductor device, the method comprising:

forming, on a semiconductor substrate, active regions that are separated by a plurality of first trenches;

forming a support in each first trench of the plurality of first trenches;

etching the active regions to define second trenches that are shallower than the plurality of first trenches;

forming spacers on sidewalls of the second trenches;

etching bottoms of the second trenches to define third trenches;

forming punch-through preventing patterns in the third trenches;

etching portions of the sidewalls that are not covered by the punch-through preventing patterns or the spacers, and forming recessed sidewalls which face each other;

forming buried bit lines in the facing recessed sidewalls;

forming a first interlayer dielectric layer on the spacers, the punch-through preventing patterns and the buried bit lines; and

forming a second interlayer dielectric layer on the first interlayer dielectric layer, to form an air gap between adjacent the buried bit lines,

wherein the second interlayer dielectric layer is filled over the air gap in top portion of the second trenches.

7. The method of claim 6, wherein forming the supports comprises:

forming a dielectric layer on an entire surface to gapfill the first trenches; and

planarizing the dielectric layer.

8. The method of claim 6, wherein forming the punch-through preventing patterns comprises:

forming a dielectric layer on an entire surface to gapfill the third trenches; and

etching the dielectric layer.

9. The method of claim 6, wherein forming the buried bit lines comprises:

forming a conductive layer on an entire surface including the recessed sidewalls; and

etching back the conductive layer.

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